The Impact of Electricity Production from Renewable Sources, Nuclear Source and the Conversion of Land Use into Agricultural Land on CO2 Emissions

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Abstract

This paper attempts to introduce factors which are linked to the sources of CO2 emissions using a standard scale, technique and composition approach. In their early work, Grossman & Krueger (1991) suggest that the impact of economic factors such as growth and trade on the environment can be decomposed into scale, technique and composition effects. Later work of Antweiler et al. (1998) provides a well-completed theoretical guideline that allows researchers to estimate separately these 3 effects. However, studies of Cole & Elliott (2003) and Managi et al. (2009), while providing partial support for Antweiler et al. (1998), show that the relationship between economic factors and pollution vary by pollutant given the differences between many common pollutants, "particularly with regards to their sources" (Cole & Elliott (2003)). Thus, this study contributes to this literature and pay attention to variables which are linked to the sources of CO2 emissions. Since electricity production and the conversion of land use into agricultural land are two main single sources of carbon dioxide emissions, I examine these impact on per capita CO2 emissions. The results of estimation for a panel of 99 countries spanning the period 1971-2010 indicate that :(1) increasing the share in electricity production from nuclear and renewable sources can decrease CO2 emissions whereas (2) the conversion of land use into agriculture land raises the amount of carbon emitted.

1 Introduction

Following Antweiler et al. (1998), economic literature on the impact of economic growth and liberal trade on environmental degradation has progressed in three main ways. Here, I report only two branches of literature that link directly to the problematic of this paper.

The first branch of the literature focus on the relationship between economic growth and environmental degradation. The main interest of these studies is to investigate in the Environmental Kuznets Curve (EKC) literature, which hypothesizes that environmental problems should first worse and then improve along to an increase of income.

The Kuznets curve is named for Kuznets (1955) who hypothesized that income inequality first rises and then falls as economic development proceeds. This hypothesis was applied to environmental issues in the later work of Grossman & Krueger (1991). Panayotou (1993) called this ”inverse U” shape environmental consequences of economic activities the Environmental Kuznets Curve. This empirical phenomenon of an inverted U relationship between GDP per capita and environmental indicators has led to a large and developing theoretical works on the mechanism involving the upward and the downward sloping of an EKC.

Numerous theoretical works provide different possible explanations for such an inverted-U relationship between economic growth and environmental problem such as inter-countries difference in abatement activities (see, for example, Smulders & Gradus (1996), Andreoni & Levinson (2001) Brock & Taylor (2010)), in institutional quality (Jones & Manuelli (1995), Jones & Manuelli (2001) pay attention on the mechanism of vote while theoretical work of Damania et al. (2003) present an interest in the role of corruption, for example), in environmental regulations (see, for example, Porter (1991), Copeland (2012)).

Compared with the findings of previous studies, Grossman & Krueger (1991) provide a very different explanation of the inverted U relationship by decomposing the impact of economic activities on environmental quality into: the negative environmental consequences of scalar increases in economic activity (scale effect), the positive impact of a greater real income on the cleaner production technique (technique effect) and the composition of output (the mix of dirty/clean industries). Whether the impact of country's mix of industries on the environment is negative or positive depend on country's comparative advantage in pollution-intensive sectors. In an ACT model, comparative advantage is considered as a function of country's endowment of capital, labor and its level of environmental regulations.

Number of empirical works support this idea. Vukina et al. (1999) suggest that the at the initial stages of economic development, emissions increase as a country develops because scale effect outweighs the composition and technique effect. By contrast, at the latter stages of development,when country specializes into clean industries, also its production's technique is cleaner, the composition and technique effects are strong enough to dominate the scale effect of growth. Thus, emissions decrease along to an increase of GDP per capita.

In this branch of literature, trade openness is considered as an important factor in generating the EKC slope. Theoretical work of Antweiler et al. (1998) implies that the impact of trade on environmental outcomes can be decomposed into trade-induced scale, trade-induced technique and trade-induced composition effect. Thus, if the EKC can be formed by combining the scale, technique and composition effect, than trade could plays an additional role in the impact of growth on environmental outcomes. Empirical evidence suggests that trade plays an important role in generating the upward sloping portion for industrializing countries by promoting exports growth of manufactured goods and downward sloping portion for industrialized countries by facilitating imports of manufactured goods (Suri & Chapman (1998)).

The second branch of the literature concentrates on the change of trade flows with liberalized trade due to inter-countries difference in level of environmental regulations. These studies ask whether dirty industries shift from rich countries with strict environmental policies (high environmental abatement costs) to poor countries with weak environmental regulations (low abatement costs), that is the so-called "industrial-flights" or "pollution havens" hypothesis. By examining the change of country's mix of industries induced by liberalized trade, this branch of literature analyzes the nature of the trade-induced composition effect. If this movement of pollution-intensity industries across countries is confirmed, then trade liberalization should lead to a decrease of pollution in rich developed countries whereas poor countries will see their emissions rise with liberal trade. At the global level, ”industrial-flights” phenomenon could harm the environment.

Among these studies, early work of Antweiler et al. (1998) (hereafter the ACT’s model) is the one that combines these two literature in one model to estimate the impact of economic growth and trade openness on the environment. On the one hand, these authors introduce the impact of economic growth on pollution outcomes by applying EKC hypothesis. And on the other hand, they also introduce the role inter-countries differences in factor abundance and environmental regulations play in the determining of trade’s pattern, thus on the compositional change of pollution induced by liberal trade. The ACT model contributes to the economic literature on the trade-growth-environment relationship in three ways:

First, ACT’s model allows us to construct a bridge between theoretical works and empirical works, which is not evident in the literature. On the one hand, the model links many controversy hypotheses involving the trade-growth-environment relationship. On the other hand, using this model, Antweiler et al. (1998) also estimate empirically the environmental outcomes of economic growth and openness to trade in 108 cities representing 43 developed and developing countries during the period 1971-1996 and found a significant relationship between trade openness and SO2 concentrations. They suggest that earlier empirical investigations failed to find a strong and convincing link between freer trade and environmental problems because they ”lacked a strong theoretical underpinning”. They also believe that with a well-completed theoretical framework, they are able ”to look in the right directions for trade’s effect”. Second, as argued by Cole & Elliott (2003), the ACT’s model is ”the only theoretical model to make a distinction between the competing effects of environmental regulations and physical capital endowments” on country’s trade pattern. Thus, ACT’s model can reveal under which economic factor, pollution intensive industries have been driven. Finally, this model also allows to estimate separately the scale, technique and composition effect of economic growth and trade on pollution outcomes.

Previous studies of Cole & Elliott (2003) and Managi et al. (2009) have shown that the relationship between economic factors and pollution can vary by pollutant given the differences between many common pollutants, ”particularly with regards to their sources” (Cole & Elliott (2003)). Thus, I suggest that factors leading to differences in carbon dioxide emissions across countries can be divided into two groups: (i) inter-countries differences in economic factors such as income per capita, capital-labor ratio and trade openness (which are captured in a standard ACT's model, for all pollutants) and (ii) inter-countries differences in appropriate factors which are linked to source of carbon dioxide. By consequent, this work attempts to capture the impact of these main sources of carbon dioxide emissions on the amount of pollution released. Two sectors are examined: energy sector and land use land use change and forestry sector (LULUCF). [1]

Among studies on the relationship between energy sector and CO2 emissions, while there have been numerous that have investigated in the relationship between energy consumption and economic growth, both in two directions, few papers including the share of total energy consumption derived from renewable sources and nuclear sources as one of potential nonpolluting factor of CO2 emissions. Apergis et al. (2010) examine the causal relationship between CO2 emissions, nuclear energy consumption, renewable energy consumption, and economic growth for a group of 19 developed and developing countries during the period 1984-2007 using a panel error correction model. The long-run estimates indicate that there is a statistically significant negative association between nuclear energy consumption and emissions, but a statistically significant positive relationship between emissions and renewable energy consumption. Menyah & Wolde-Rufael (2010) using time series econometrics of integration and causality method to explore the causal relationship between carbon dioxide (CO2) emissions, renewable and nuclear energy consumption and real GDP for the US for the period 1960-2007. They found a unidirectional causality running from nuclear energy consumption to CO2 emissions but no causality running from renewable energy to CO2 emissions.

Several studies including renewable and non-renewable energy consumption as additional variables in an EKC estimation [2]. Jebli et al. (2016) find that more trade and

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[1] Le Quéré et al. (2013) cite burning fossil fuel for energy sector (Figure 1 shows the increasing trend of world CO2 emissions from burning fossil fuel during the period 1960-2010) and land use change due to the expansion of agriculture sector top the list of human sources of CO2 emissions.

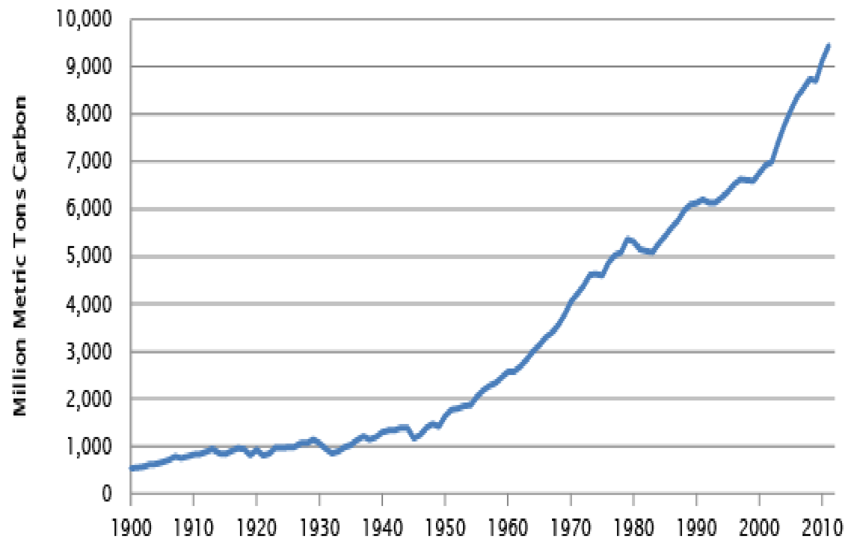
[2] The following equation is the traditional and dominant technique in the EKC literature using cross-sectional data: [3].

$$E_{it} = \alpha_i + \gamma_t + \beta_1 y_{it} + \beta_2 (y_{it})^2 + \beta_3 (y_{it})^3 + \beta_4 Z_{it} + \epsilon_{it}, \tag{1}$$

where E is environmental indicators, y is per capita income, α captures site or country specific term i, γ refers to time specific term t. The vector Z capture other additional variables as population density, locational dummies, etc.

more use of renewable energy help to reduce CO2 emissions in 25 OECD countries during the period 1980-2010 while adding these factors as additional variables in an quadratic form of the pollution-income equation. Similarly, Bilgili et al. (2016) argue that renewable energy consumption leads to CO2 reductions for a panel of 17 OECD countries during the period 1977-2010.

Figure 1: Global CO2 emissions and CO2 emissions from burning fossil fuel: 1900-2011



Source: Marland et al. (2007)

While the evidence of an negative correlation between energy consumption from nuclear source and the amount of carbon released has been founded in previous studies, the role of renewable energy on CO2 reductions is still inconclusive.

After burning fossil fuel for energy sector, land use change due to the expansion of agriculture sector top the list of human sources of CO2 emissions (Le Quéré et al. (2013)). Empirical studies usually concludes that LULUCF sector is an important source of CO2 emissions [4] and global net annual emissions of carbon from land use

[4]for instance, R. Houghton & Hackler (1999) found that the emissions of carbon from land-use change in the 1980s accounted for approximately 75 % of the regionŠs total carbon emissions in tropical Asia

and land-use change increases gradually (R. A. Houghton (2010)).

Among number of activities in the LULUCF sector, the conversion of land could lead to both CO_2 emissions and removals: land converted to forest land and grassland are two major sources of CO_2 sequestration whereas land converted to agricultural land [5] and settlements are two major sources of CO_2 emissions (Hallsworth & Thomson (2011)). Thus, there is also a large literature on the impact of urbanization and agriculture on emissions (Vleeshouwers & Verhagen (2002), Kalnay & Cai (2003), Vanum (2012)). Recent studies also examine the impact of the use of crop-lands for bio-fuels on greenhouses gases. (Searchinger et al. (2008)).

Literature on the impact of land use change on CO_2 emissions provides a chemistry/biology explanation of this phenomenon. Nowhere, however, examine this relationship under an economic view and put the impact of land use change and economic factors side by side and estimate its impact on pollution outcomes. Thus, there is a need to examine the impact of land use change on CO_2 emissions.

By examining the impact on CO_2 emissions of the share of electricity production from nuclear and renewable sources, also the share of agricultural land on total land, this work is novel for 2 points: (i) the first one that examines the causal relationship between the sources of electricity production and the conversion of land into agricultural land on CO_2 emissions and (ii) the first one that attempts to control for variables which are linked to the sources of emissions in a standard ACT's model.

Using a large panel of 99 countries over the period 1971-2010, this study also provides a global view on how these factors can affect environmental quality around the world. The results of estimation indicate that for one unit increase in the share of electricity production from nuclear source, CO_2 emissions per capita is expected to decrease by 1 unit. And CO_2 emissions per capita could increase by 2 units if the share of agriculture increases by 1 unit, holding all other variables constant. Thus, this study confirms the positive effect on the environment of fuel-switching for the production

[5] Most of these LULUCF emissions are intimately connected to agriculture, as many resulted from deforestation caused by expansion of farms into tropical forests (Van der Werf et al. (2009)). The conversion of land from forested to agricultural land can have a wide range effect on CO_2 emissions. As introduced by the EPA (United States Environmental Protection Agency), "in countries where large areas of forest land are cleared, often for agricultural purposes or for settlements, the LULUCF (Land use, Land use change, Forestry) sector can be a net source of GHGs emissions".

of energy; also the negative effect of the conversion of land use into agriculture land on environmental quality.

This paper is organized as follow: section 2 presents the scale, technique and composition approach in the ACT's model, also my suggestion to decompose carbon dioxide emissions from electricity production and land use conversion into scale, technique and composition effects; section 3 shows the strategy of estimation, the problem of endogeneity while examining the trade-growth-environment relationship, and data description. Section 4 reports the results of estimations. Finally section 5 concludes.

2 Scale, technique, composition approach

The scale-technique-composition approach is prime concern of this paper in two ways. First, the model and methodology of Antweiler et al. (1998), which is the central focus of this study, based on the decomposition of economic factors on pollution outcomes through the scale, technique and composition effects. Second, the effects of energy sector and LULUCF sector on CO2 emissions are decomposed into scale, technique and composition effects. Thus, this decomposition shows variables linked with these main sources of CO2 emissions and that are not already controlled for by the other explanatory variables in an ACT estimation.

2.1 ACT's model

To begin with, it is useful to provide a brief summary of the ACT's model and the method of decomposition of pollution. The key purpose of the ACT model is a simple general equilibrium model when government policy and private sector behavior interact to determine the equilibrium level of pollution. According to these authors, the government determines the level of taxes on emissions τ that maximizes the sum of utility of N agents in economy. Through the level of τ, the government decides the supply of the pollution. In another hand, private sector behavior considers pollution emissions as a sacrifice to economic activities (because they should pay emissions tax τ and decides the pollution demand. Combining the two functions of pollution demand and supply yields the reduced form of pollution emissions equation. A brief outline of the model is presented below.

Consider a small economy open economy that faces fixed world prices and produces two goods X and Y. Good X is capital intensive and therefore generates pollution during its production and good Y does not (Y is labor intensive) [6]. Consequently, the X industry jointly produces two outputs-good X and emissions Z. Let β denote the wedge between domestic and world prices induced by trade frictions (the direct and indirect costs associated with good transaction), if p^x is the relative price of X (good Y is the numeraire, $p_y = 1$) then domestic prices will differ from world prices (p^w), the function of domestic price can be written as:

$$p^x = \beta p^w \tag{2}$$

More precisely, $\beta > 1$ if country is a dirty good X importer and $\beta < 1$ if country is a dirty good X exporter. ACT define trade liberalization as the gradual reduction in trade frictions that moves domestic price closer to world prices. Consequently, from equation (2), for an exporter of polluting good X, β rises with freer trade and this also raises the relative price p of the dirty good X. The composition of national output shift toward X. By contrast, β falls with freer trade for an importer of the polluting good and this also lowers the relative price p of the dirty good X. Consequently, the composition of national output shift toward clean industry Y.

Let focusing on the supply and demand side of emission Z. On the supply side, suppose that firms face a price τ (imposed by the government) for each unit of emission they generate. The level of τ reflects the supply side of the emission Z. The government preferred a level of pollution tax that maximizes the weighted sum of each group's utilities. The composition of pollution supply is:

$$\widehat{\tau} = \widehat{Type} + \delta_1 \beta + \delta_2 \widehat{p^x} + \delta_3 \widehat{INC} \tag{3}$$

The level of emissions tax depends on the proportion of "Greens" and "Browns" [7]

[6] That means, for any r and w (market returns for K and L), the capital / labor ratio in X is higher than Y: $\frac{K_x}{L_x} > \frac{K_y}{L_y}$

[7] two citizen groups whom differ in their preferences over pollution

in this country (variable $Type$), the price level of dirty good X p^x, country's trade friction β and country's real per capita income INC.

On the demand side, emission z is defined as:

$$z = ex = e\varphi S \tag{4}$$

Where e is emission intensity (the proportion of emission z for each unit of output x), φ is the share of X in total output. Finally, S is defined as an economy's scale [8]. In differential form it becomes

$$\widehat{z} = \widehat{e} + \widehat{\varphi} + \widehat{S} \tag{5}$$

Where the composition of output $\varphi = \varphi$(k, p(β, p^w, τ)), pollution intensity e = e(τ, p(β, p^w, τ)) Replacing τ in the pollution demand equation on the pollution supply yields the equilibrium reduced form equation of emissions z:

$$\widehat{z} = \pi_1\widehat{S} + \pi_2\widehat{k} - \pi_3\widehat{INC} - \pi_4\widehat{Type} + \pi_5\widehat{p^w} + \pi_6\widehat{\beta}, \tag{6}$$

Where all π_i are positive, and none of the right hand-side variables are determined simultaneously with emissions. Emission z depends on: the scale of economic S, the composition of country's factor abundance (k/l ratio), the cleanliness of production technique (GDP per capita INC), the type of country (the proportion of "Greens" and "Browns" T), world's price of dirty good X (p^w) and finally trade friction (β).

The ACT framework provides a standard guideline on how growth and trade cause environmental problems, not for some specific ones. Cole & Elliott (2003) have shown that the relationship between economic pollutants and pollution can vary by pollutant given the differences between many common pollutants, "particularly with regards to their sources". Thus, I focus therefore on the main sources of carbon dioxide emissions.

[8] S = p_x^0x + p_y^0y

2.2 Decomposition of emissions from energy sector and LULUCF sector

2.2.1 The need to introduce the sources of pollutant

Why ignoring the sources of different pollutant can bias the results of estimation ?. Recall the decomposition of pollution emissions at country level:

$$z = ex = e\varphi_x S \tag{4}$$

Pollution emissions depends on the emissions intensity of production e, the proportion of the dirty good industry in the economy φ_x, and finally the scale of economy S. We can rewrite equation (4) as:

$$z = S * \frac{x}{S} * \frac{z}{x} \tag{7}$$

Pollution emissions z depends on the scale of economy S, the proportion of the dirty good industry in the economy $\frac{x}{S}$, and finally the amount of pollution emitted z on each unit of x produced $\frac{z}{x}$. Economic factors such as GDP/km^2 (scale effect, refers to S), capital/labor ratio (composition effect, refers to $\frac{z}{x}$ and GDP per capita (technique effect, refers to $\frac{z}{x}$) provide a general view on how economic growth affect on pollution outcomes.

At industry level, total pollution from manufacturing, Z, can be written as the sum of pollution from each of its component industries z_i. This in turn can be written as the total value shipped from manufacturing, S, multiplied by the sum of each industry's share of total output, ($\varphi = \frac{x_i}{S}$) times amount of pollution per dollar of value shipped in this industry, ($e_i = \frac{z_i}{x_i}$) (see, for instance, Levinson (2007))

$$Z = \sum z_i = S \sum \frac{x_i}{S} * \frac{z_i}{x_i} \tag{8}$$

Here I suggest, for example, the decomposition of CO2 emissions and SO2 emissions. [9] The main sources of CO2 emissions are burning fossil fuels, land use land use change

[9] see also Levinson (2007) for decomposition analysis at industry-level

and forestry sector, and industrial process. Total amount of CO2 emitted through these 3 sectors can be decomposed into:

$$z_{CO2} = S_{energy} \sum \frac{x_i}{S_{energy}} * \frac{z_i}{x_i} + S_{LULUCF} \sum \frac{x_j}{S_{LULUCF}} * \frac{z_j}{x_j} + S_{Indus} \sum \frac{x_k}{S_{Indus}} * \frac{z_k}{x_k} \quad (9)$$

Similarly, the main sources of SO2 emissions are burning fossil fuels and industrial process.

$$z_{CO2} = S_{energy} \sum \frac{x_i}{S_{energy}} * \frac{z_i}{x_i} + S_{Indus} \sum \frac{x_k}{S_{Indus}} * \frac{z_k}{x_k} \quad (10)$$

Assuming that country's government decided to implement a new policy of land management in favor of the environment (a afforestation for example), thus this environmental friendly policy can to lower CO2 emissions in this country whereas the level of SO2 emissions remains unchanged. This simple example shows that ignoring the sources of pollutants may be problematic while using the ACT's model.

2.2.2 Simple decomposition of emissions from electricity production and land use conversion

To simplify, I focus therefore on the pollution generated from electricity production (largest single source of CO2 emissions from energy sector) and from the conversion of land use into agricultural land (the largest single source of CO2 emissions from LULUCF sector)

Electricity production

The amount of pollution being released is the sum of pollution emitted through raw non-renewable (raw) sources, renewable sources and nuclear sources. Thus, I suggest that the amount of pollution released from electricity production can be decomposed as follows:

$$z_{electric} = S_{electric} * \frac{s_{raw}}{S_{electric}} * \frac{z_{raw}}{s_{raw}} + S_{electric} * \frac{s_{renewable}}{S_{electric}} * \frac{z_{renewable}}{s_{renewable}} + S_{electric} * \frac{s_{nuclear}}{S_{electric}} * \frac{z_{nuclear}}{s_{nuclear}} \quad (11)$$

Total emissions from the production of electricity sector $z_{electric}$ depend on: (i) the scale of this sector $S_{electric}$ (scale effect); (ii) the amount of pollution emitted by using non-renewable, renewable and nuclear sources ($\frac{z_{raw}}{s_{raw}}$; $\frac{z_{renewable}}{s_{renewable}}$ and $\frac{z_{nuclear}}{s_{nuclear}}$, respectively)[10] and (iii) the share of non renewable, renewable and nuclear sources in the production of electricity ($\frac{s_{raw}}{S_{electric}}$, $\frac{s_{renewable}}{S_{electric}}$ and $\frac{s_{nuclear}}{S_{electric}}$ respectively.

The composition effect of energy sector can be shown through different sources of energy production. In fact, among several sources of energy production [11], some generated more emissions than others. Thus, the "composition" of these different sources should have a significant impact of the compositional change of CO2 emissions. Producing more energy from renewable sources and using fuels with lower carbon contents are ways to reduce carbon emissions.That is the so-called "fuel-switching" phenomenon.

The sources of electricity production can be divided into 3 groups: non-renewable sources (minerals, coal, oil, gas); renewable sources (including hydro-power, biomass, geothermal, solar, wind) and nuclear source. The chart below show that generating electricity from fossil fuels causes GHGs far higher than when using nuclear or renewable sources (particularly solar and wind energy, which provide electricity without giving rise to any carbon dioxide emissions).

The conversion of land use into agricultural land

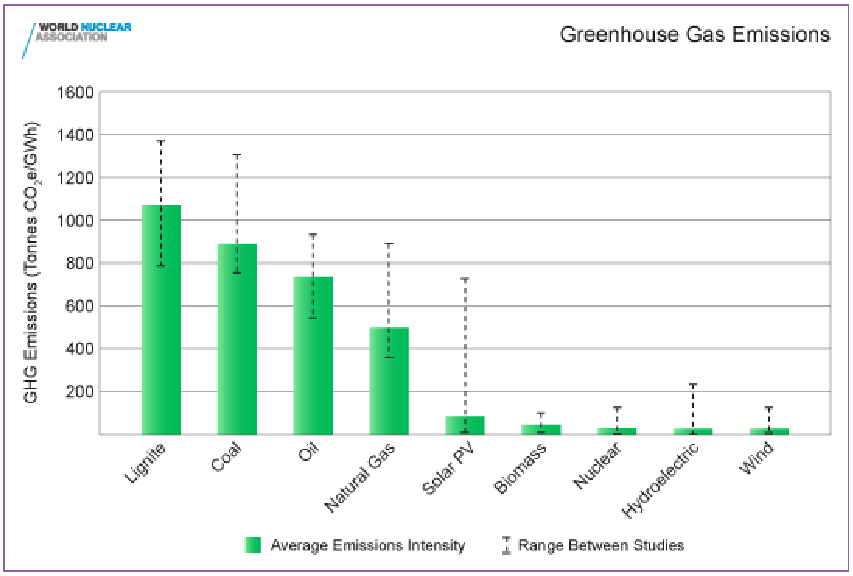
The amount of CO2 emitted due to the conversion of land use is the sum of pollution emitted through the conversion of land use into agricultural land and settlements.

$$z_{LULUCF} = Land * \frac{land_{agriculture}}{Land} * \frac{z_{agriculture}}{land_{agriculture}} + Land * \frac{land_{settlements}}{Land} * \frac{z_{settlements}}{land_{settlements}}, \quad (12)$$

[10]For energy sector, technique effect is shown through "energy efficiency". Energy efficiency means "using less energy to provide the same service". Following Patterson (1996), energy efficiency is defined as the ratio of useful output of a process on energy input into a process. Thus, the higher the rate of energy efficiency, the lower emissions generated.

[11]Coal, natural gas, nuclear, hydro-power, biomass, geothermal, solar, wind, petroleum, other gases.)

Figure 2: Greenhouse Gas Emissions from different forms of electricity generation



The amount of CO2 emitted from land use conversion depend on total land use (scale effect), pollution emitted by using land converted to agricultural activities and settlements ($\frac{z_{agriculture}}{land_{agriculture}}$ and $\frac{z_{settlements}}{land_{settlements}}$ respectively), also the share of agricultural land and settlements land in total land.

3 Model, Adressing Endogeneity and Data

3.1 Strategy of estimation

First, I employ a specification similar to those of Cole & Elliott (2003) and Managi et al. (2009), where the determinants of emissions per capita at country-level using an ACT framework can be written as:

$$\begin{aligned} E_{it} =& \alpha_0 + \alpha_1 KL_{it} + \alpha_2 (KL_{it})^2 + \alpha_3 INC_{it} + \alpha_4 (INC_{it})^2 + \alpha_5 KL_{it} INC_{it} \\ &+ \alpha_6 T_{it} + \alpha_7 T_{it} Rel.KL_{it} + \alpha_8 T_{it} (Rel.KL_{it})^2 \\ &+ \alpha_9 T_{it} REL.INC_{it} + \alpha_{10} T_{it} (Rel.INC_{it})^2 + \alpha_{11} T_{it} Rel.KL_{it} Rel.INC_{it} \\ &+ Pollutant_{it} + \epsilon_{it}, \end{aligned} \quad (13)$$

Where the income term (INC) is GDP per capita, KL is the national capital-to-labor ratio, T is the trade intensity (exports plus imports on GDP), REL.KL is country k's capital-to-labor ratio measured relative to the world average, and REL.INC is country k's real income per capita measured relative to the world average.

The income term (INC) and its quadratic (INC^2) capture the scale-technique effect of economic activity on emissions. The capital-labor term (KL) and its quadratic (KL^2) capture the effect of factor abundance on the compositional change of emissions. The interaction term (INC*KL) refers to the impact of an increase of income per capita on emissions at a given level of capital-labor ratio and vice-versa.

Trade intensity variable T represents the direct effect of trade openness on the compositional changes of pollutions emissions. The interaction between trade intensity and relative capital $T^*Rel.KL$, also its quadratic term $T^*(Rel.KL)^2$ refer to the KLE hypothesis: countries that have comparative advantage in capital-intensive sectors (which are also pollution-intensive sectors) will see its emissions raise with trade liberalization. Alternatively, countries that have comparative advantage in labor-intensive sectors will see its emissions fall with trade. The interaction between trade intensity and relative income $T^*Rel.INC$, also its quadratic term $T^*(Rel.INC)^2$ refer to the EKE hypothesis: countries that have relative weak environmental regulations (also relative poor countries) will specialize in the pollution-intensive sectors whereas countries with higher environmental stringency will specialize in clean industries.

$Pollutant_{it}$ is a vector that captures variables which are linked to the sources of the concerned pollutant. Because the ACT's model don't account for the sources of pollutant, in equation (13), $Pollutant_{it} = 0$. Equation 13 refers to Model A, which is a standard ACT equation. An estimation of model A can help to (i) compare the results with previous studies and (ii) verify whether an investigation for a standard ACT equation in the case of carbon dioxide is necessary.

Accounting for the share of renewable sources and nuclear source in the production of electricity, also the conversion of land use into agricultural land, the vector $Pollutant_{it}$ in Model A becomes:

$$Pollutant_{it} = \alpha_{12} Nuclear - Energy_{it} + \alpha_{13} Renewable - Energy_{it} + \alpha_5 Agriculture_{it} \tag{14}$$

Where $Nuclear - Energy_{it}$ and $Renewable - Energy_{it}$ refer to the share of electricity production from nuclear and renewable sources of country i at time t, respectively. The variable $Agriculture$ measures the share of agricultural land on total area. I refer to this amended form of equation (13) as Model B.

3.2 Adressing Endogeneity

Endogeneity is a common problem that occurs empirical literature on the trade-growth-environment relationship. Cole & Elliott (2003) argue that the causal direction among each pair out of these three key variables is not evident.

On the one hand, many believe that changes in per capita income will lead to higher demand for environmental quality. Both trade and growth affect per capita income, thus openness to trade and economic activities could have important effect on environmental quality. [12]

[12] see, for example, Jones & Manuelli (2001)

On the other hand, environmental policy can also affect economic activities and trade pattern through higher level of environmental abatement costs. That is, environmental policy could have an adverse effect on trade and economic activities.

In the case of endogeneity problem, instrumental variables (IV) are considered as an estimation that provide consistent parameter estimates. Note that an valid instrument should highly exogenous yet correlated with endogenous variable and uncorrelated with the error term.

First, standard approach to construct an instrument for trade share is proposed by Frankel & Romer (1999). These authors argue that country' geography characteristics (as its distance with others, its population, etc.) should have important effects on trade and are plausibly uncorrelated with other determinants of income. Consequently, geography's component of country's trade seems to be a good instrument of openness to trade.

Second, following Managi et al. (2009), to construct an instrument for income per capita, I use a set of variables from the endogenous growth equation. Note that, trade is also endogenous in income equation. That is, country that is rich for reason other than trade may trade more [13]. By consequent, geography's component of trade share is used as an instrument for real trade share variable in income equation.

The Frankel & Romer's method to construct an instrument for trade share also the Managi et al. (2009) method to construct an instrument for income per capita are reported in Appendix A and B, respectively.

3.3 Data

The study covers 99 countries from Asia (24), Europe (23), Africa (29), America (23) from 1971 to 2010. Table 1 displays summary statistics for the sample. Data of CO2 emissions per capita, the share of electricity production from nuclear source and renewable source, also the share of agricultural land on total land are from World Development Indicators - World Bank Database. Data on trade intensity (at 2005

[13] see, for example, Dollar & Kraay (2004)

constant price), capital, population and real GDP per capita (2005 US$) come from Penn World Table 8.1.

Table 1: Descriptive Statistics

Variable	Dimension	Obs	Mean	Std.	Min	Max
CO2 emissions per capita	tons	3960	4.317928	5.901309	.016115	67.4166
GDP per capita	$ 10k	3960	1.017623	1.226213	.016093	9.796309
Capital/Labor ratio	$ 10k/worker	3960	6.375212	7.217392	.0957449	52.85397
Relative per capita GDP	Dimensionless	3960	.9850296	1.166349	.015525	9.544766
Relative Capital/labor ratio	Dimensionless	3960	.9263247	1.036363	.0151855	9.698598
Exports plus imports/GDP	Per cent	3960	.6819743	.4864387	.0316	4.3305
Renewable energy	Per cent	3360	.0217085	.0511931	0	.6259649
Nuclear energy	Per cent	3360	.0475197	.1273073	0	.7909981
Agricultural Land	Per cent	3880	.3954565	.2140539	.01	.9055524

Table 3.3 reports pairwise correlation for the variables of interest. The table indicates a strong correlation between CO2 emissions per capita and real income per capita (at 76 %), a moderate correlation between CO2 emissions per capita and trade intensity. We also observe a greater correlation between capital-labor ratio and GDP per capita, that is rich countries is also capital-intensive countries.

Table 2: Pairwise correlation of variables of interest

	CO2 per capita	GDP per capita	Trade Intensity	Capital-labor ratio
CO2 per capita	1.0000			
GDP per capita	0.7607	1.0000		
Trade Intensity	0.2857	0.2922	1.0000	
Capital-labor ratio	0.7682	0.9078	0.3013	1.0000

4 Results

Table 4.A shows results of estimation of Model A.

Considering the non-trade variables: the results indicate a significant and positive relationship between per capita GDP and pollution in all specifications .Thus, scale dominates technique effect in the case of carbon dioxide emissions. The dominant

Table 4.A: The determinants of CO2 emissions per capita

	OLS	Within	GLS	Within	GLS
Individual Effect	No	Fixed	Random	Fixed	Random
Intrument	No	No	No	Yes	Yes
INC	1.401***	0.722***	0.822***	2.112***	2.186***
	(12.61)	(8.92)	(10.24)	(7.56)	(8.19)
INC^2	0.0127	0.0545*	0.0455*	-0.344**	-0.328**
	(0.31)	(2.55)	(2.11)	(-2.94)	(-2.94)
KL	0.355***	0.140***	0.150***	-0.0751+	-0.0584
	(19.60)	(10.70)	(11.47)	(-1.70)	(-1.41)
KL^2	-0.00689***	-0.00113	-0.00147*	0.00317+	0.00275+
	(-5.71)	(-1.55)	(-2.00)	(1.92)	(1.76)
KL*INC	-0.0667***	-0.0428***	-0.0433***	-0.0161	-0.0195
	(-5.15)	(-5.81)	(-5.84)	(-0.72)	(-0.89)
T	0.918***	0.357***	0.338***	1.716***	1.542***
	(16.72)	(8.80)	(8.32)	(7.46)	(7.49)
T*Rel INC	-0.518***	-0.320***	-0.364***	-1.684***	-1.675***
	(-4.58)	(-5.20)	(-5.88)	(-6.73)	(-7.05)
$T*(RelINC)^2$	0.0329	0.0267	0.0358*	0.375***	0.364***
	(1.02)	(1.63)	(2.16)	(3.97)	(4.05)
T*Rel KL	-0.819***	-0.247***	-0.237***	0.653**	0.645**
	(-7.32)	(-3.90)	(-3.70)	(2.67)	(2.79)
$T*(RelKL)^2$	0.192***	0.0860***	0.0938***	0.0233	0.0321
	(5.10)	(4.79)	(5.17)	(0.57)	(0.83)
T*Rel INC*Rel KL	0.125+	0.000821	-0.00643	-0.199+	-0.193+
	(1.83)	(0.03)	(-0.20)	(-1.78)	(-1.80)
_cons	-1.939***	-0.638***	-0.723***	-1.256***	-1.274***
	(-47.74)	(-17.52)	(-8.34)	(-15.10)	(-8.35)
N	3960	3960	3960	3960	3960
adj. R^2	0.738	0.178			
Hausman test		358.67		20.51	
Prob¿chi2		0.000		0.038	

t statistics in parentheses, $^+$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. In IV estimation, trade openness, per capita GDP and its square term are instrumented for using predicted openness, predicted per capita GDP, and predicted its square term, respectively.

scale for CO2 emissions has been founded in previous studies. The sign of INC^2 is positive in the case of OLS (insignificant), GLS and Within estimation (at .1 significance level) but statistically negative in the case of IV estimations (at .05 significance level). This result seems to be similar with Managi et al. (2009), who found statistically insignificant relationship between INC^2 and CO2 emissions in the case of OLS but statistically negative in the case of GMM estimation, also with Cole & Elliott (2003) who find no evidence of a relationship between quadratic term of income and CO2 emissions using fixed and random effects estimations.

With regard to the composition effect of economies: both two previous studies found that increases in KL also increase per capita CO2 emissions. Managi et al. (2009) also found that each additional increase in KL has a diminishing impact (the sign of $(KL)^2$ is negative with statistical significance). Results in table 4.A indicate that an increase in KL will increase per capita emissions with diminishing effect only while using OLS, Random and Fixed effect estimations. IV estimations yield a statistically insignificant relationship between capital-labor ratio and pollution.

The interaction term $INC * KL$ refers to the impact of an increase in income per capita at a given level of capital/labor ratio and vice versa. Studies of Cole & Elliott (2003) and Managi et al. (2009) provide different results by method of estimation: significantly negative (OLS), insignificant (fixed and random effect), significantly positive (GMM). Results in column (1), (2), (3) show that the cross-product of K/L and S is negative with statistically significance while using OLS, Within and GLS as estimation method. However, the coefficient becomes insignificant while using IV estimation (column (4) and (5)).

Considering the trade variables: Table 4.A predicts a strong and significantly positive correlation between trade intensity and emissions (at .01 significance level for all specifications). The coefficients of estimation of the ERE are very similar with those of Managi et al. (2009): the sign of $T_{it}Rel.INC_{it}$ is negative with statistical significance for all specifications at an increasing rate (the sign of $T_{it}(Rel.INC_{it})^2$ is negative for all specifications. The sign of $T_{it}Rel.KL_{it}$ changes with estimation method: positive in the case of Instrumental Variable estimation (both fixed and random effects), negative in the case of OLS, GLS and Within Estimation; and at increasing rate : the sign of $T_{it}(Rel.INC_{it})^2$ is positive for all specifications (but insignificant in the case of IV estimations).

Finally, the results for $T_{it}Rel.KL_{it}Rel.INC_{it}$ are quite similar with those of Managi et al. (2009): significantly positive (OLS), insignificant (Within, GLS) and significantly negative (IV, GMM).

Table 4.B presents the results of OLS, Random effect estimation GLS and Random effect with instrumental variables estimation of the emissions of CO2 per capita using the full dataset.

Column (1), (2), (3) shows the results of estimations without the set of trade variables proposed by ACT while in column (4), (5) and (6) the set of variables that present the trade-induced composition effect. In all columns, the sign of Nuclear-Energy is negative at the .01 significance level. The result indicates that an increase in the share of nuclear energy as a source of electricity production should help to lower CO2 emissions per capita. GLS estimation and GLS with instrumental variables estimations show that for one unit increase in the share of nuclear energy on total sources of electricity production, CO2 emissions per capita is expected to decrease by 1 unit, holding all other variables constant. Results from OLS estimation (column (1) an (4)) seem to underestimate the impact of using nuclear energy compared to other methods of estimation.

Table 4.B also indicates that increasing the share of renewable energy in electricity production (the Renewable-energy term) could lower pollution emissions. However, the significance level of this variable changes substantially over estimation method (at the .01 significance level for OLS estimation, .05 significance level for GLS estimation and .1 significance level for GLS-IV estimation).

The effect of an increase in the share of agricultural land is positive at the .01 significance level in all columns. Results in column (2) and (3) indicate that, CO2 emissions per capita could increase by 2 units if the share of agriculture in total land increases by 1 unit, holding all other variables constant.

While adding up the set of trade-induced composition effect proposed by ACT, the coefficients of additional variables don't lose their significance, except for $Renewable-energy$, however the coefficient remains significant.

Table 4.B: The role of Nuclear Energy, Renewable Energy and Land-Use Change on CO2 emissions

	Model A		Model B			
	Within	2SLS	Within	2SLS	Within	2SLS
	(1)	(2)	(3)	(4)	(5)	(6)
INC	0.722***	2.186***	0.637***	1.963***	0.811***	1.485***
	(8.92)	(8.19)	(8.66)	(6.09)	(10.21)	(4.50)
INC^2	0.0545*	-0.328**	0.0620**	-0.491**	0.115***	-0.912***
	(2.55)	(-2.94)	(3.22)	(-3.15)	(4.73)	(-3.94)
KL	0.140***	-0.0584	0.138***	-0.0575	0.137***	-0.0285
	(10.70)	(-1.41)	(11.43)	(-1.10)	(11.25)	(-0.88)
KL^2	-0.00113	0.00275+	-0.000683	-0.000813	0.000799	-0.0113**
	(-1.55)	(1.76)	(-1.01)	(-0.47)	(1.11)	(-3.08)
KL*INC	-0.0428***	-0.0195	-0.0423***	0.0378	-0.0638***	0.185**
	(-5.81)	(-0.89)	(-6.19)	(1.27)	(-8.02)	(2.84)
T	0.357***	1.542***	0.301***	1.582***	0.232***	1.477***
	(8.80)	(7.49)	(7.39)	(6.32)	(5.56)	(4.31)
T*Rel INC	-0.320***	-1.675***	-0.232***	-1.565***	-0.303***	-0.780**
	(-5.20)	(-7.05)	(-4.20)	(-5.13)	(-4.83)	(-2.64)
$T * (RelINC)^2$	0.0267	0.364***	0.00503	0.445***	-0.0682**	0.830***
	(1.63)	(4.05)	(0.35)	(3.58)	(-3.14)	(3.84)
T*Rel KL	-0.247***	0.645**	-0.311***	0.523+	-0.254***	-0.0172
	(-3.90)	(2.79)	(-5.48)	(1.84)	(-4.28)	(-0.08)
$T * (RelKL)^2$	0.0860***	0.0321	0.0693***	0.107*	0.000792	0.516**
	(4.79)	(0.83)	(4.24)	(2.46)	(0.04)	(3.23)
T*Rel INC*Rel KL	0.000821	-0.193+	0.0311	-0.361*	0.182***	-1.228**
	(0.03)	(-1.80)	(1.05)	(-2.47)	(4.22)	(-3.07)
Nuclear_Energy			-1.222***	-1.088***	-1.252***	-1.492***
			(-12.12)	(-6.65)	(-11.56)	(-7.99)
Renewable_Energy			-0.647***	-0.531***	-0.647***	-0.488***
			(-13.49)	(-7.59)	(-13.51)	(-6.73)
Agriculture					1.796***	1.046**
					(9.50)	(3.19)
_cons	-0.638***	-1.274***	0.0195	-0.588***	-0.805***	-0.886***
	(-17.52)	(-8.35)	(0.45)	(-5.95)	(-9.35)	(-6.46)
N	3960	3960	3280	3280	3200	3200
adj. R^2	0.178		0.9586		0.9584	
Hausman	199.54		517.21		143.09	
Prob¿chi2	0.000		0.000		0.000	

t statistics in parentheses, $^+$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. In IV estimation, trade openness, per capita GDP and its square term are instrumented for using predicted openness, predicted per capita GDP, and predicted its square term, respectively.

5 Conclusion

While regarding the impact of the composition of an economy on pollution outcomes using a standard ACT specification, I ask whether for a given pollutant there is necessary to adding up variables that link directly to its sources. Thus, I focus on two main sources of CO2 emissions, energy sector and LULUCF sector and therefore controlling for the share of renewable and nuclear energy in total source of electricity production also the share of agricultural land on total land, respectively. Results of estimation show that (1) increasing the share of nuclear source in total source of electricity production lowers the amounts of CO2 emitted; (2) even if the variable that refer to the share of renewable source in total source of electricity production is insignificant in several specifications, but for almost estimations, the results indicate that using renewable source for the production of electricity is environmental friendly. Note that in all specifications, it appears that the magnitude of the former is greater than the latter in term of reduction of CO2 emissions; (3) and, for almost specifications, the results show that increasing the share of agricultural land in total land could cause significant detrimental impact on the environment by generating more carbon dioxide.

This study confirms the positive effect on the environment of fuel-switching for the production of energy; also the negative effect of the conversion land use change into agriculture land on environmental quality. Thus, while the debate over the impact of growth and trade on the environment is still inconclusive, there is a need to focus on the sources of important pollutants, in order to reduce the amount of pollution emitted through human activities. For instance, improving energy efficiency, switching fuel, limiting the deforestation are several solution to cut off carbon dioxide emissions.

Appendix A. Gravity Equation

The Frankel and Romer version of a gravity equation was rewritten as:

$$ln(\tau_{ij}/GDP_i) = \beta_0 + \beta_1 lnD_{ij} + \beta_2 lnN_i + \beta_3 lnA_i + \beta_4 lnN_j +_5 lnA_j + \beta_6(L_i + L_j)$$
$$+\beta_7 B_{ij}+\beta_8 B_{ij}lnD_{ij}+\beta_9 B_{ij}lnN_i+\beta_{10}B_{ij}lnA_i+\beta_{11}B_{ij}lnN_j+\beta_{12}B_{ij}lnA_j+\beta_{13}B_{ij}(L_i+L_j)+\sigma_{ij}, \quad (15)$$

Where N is their population, A is their area, L is a dummy for landlocked countries, B is a dummy for a common border between two countries. Variables from α_8 to α_{13} represent geographical interactions between two countries whether they share a common border. This version of gravity equation can provide more information about bilateral trade on one hand, and on the other hand, to ensure that only country' geographic characteristics have been used to estimate openness to trade between two countries.

The reduced form of equation (15) is :

$$ln(\tau_{ij}/GDP_i) = a'X_{ij} + e_{ij}, \quad (16)$$

Here, X_{ij} is the vector of variables representing geographic characteristics of country i and j.
Secondly, these authors suppose that if geography is a component of bilateral trade, than it's true for overall trade. The simple collection of data about geographic characteristics of all countries supports enough information about the level of openness to trade.

$$\hat{T}_i = \sum_{i \neq j} e^{\hat{a'} X_{ij}}, \quad (17)$$

Equation (17) examines the construction of international country's overall trade after obtaining the vector of coefficient α' in equation (16). International trade's level of country i is simply knowing as an aggregate of its trade with each other countries in the world.

Appendix B. Income Equation

We use an income equation similar to Managi et al. (2009). Following the endogenous growth literature, country's income depend on its lagged values, trade openness, capital-labor ration, population and humain capital. Income equation can be written as:

$$lnINC_{it} = \lambda_0+\lambda_1 lnINC_{it-1}+\lambda_2 lnT_{it}+\lambda_3 ln(KL)_{it}+\lambda_4 lnP_{it}+\lambda_5 lnSch_{it}+\lambda_6 year_t+\mu_{it} \tag{18}$$

where P is the population, Sch is index of human capital based on school attendance years, μ is the error term.

Table 5 shows results of the difference GMM estimation using instrumental variables for the income equation 18. As mentioned in the introduction, I treat trade share as endogenous in the income equation and therefore use predicted value of trade share as an instrument for real trade intensity.

Table 5: Income Equation

	lnIncome
L.lnIncome	0.798***
	(39.08)
lnT	0.100***
	(9.32)
lnP	0.0327
	(1.44)
lnKL	0.0329+
	(1.76)
lnSch	-0.165*
	(-2.57)
year	0.00180**
	(2.69)

t statistics in parentheses

$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

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